SMART UXO SYSTEM – SOLUTION TO REAL-TIME UXO DETECTION

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Abstract

Improvements in unexploded ordnance (UXO) detection and false alarm rates during clearance operations is central to increased efficiency and reduced cost. The Corps of Engineers has indicated that reducing false alarm rates is their number one priority for expediting UXO remediation work.

This paper describes the development and preliminary testing of a field-deployable UXO detection system. This system, referred to as a “Smart UXO System,” incorporates specialized data analysis technology to implement real-time UXO detection and classification techniques. The system is designed for onsite in the field operation. This innovation will augment the UXO field operator’s capabilities, streamline operations, improve detection efficiency, and significantly reduce clearance costs. The Smart UXO System approach will increase operator capabilities to detect UXO in real time, and provide the means for fast, effective, and accurate classification of targets in the field. This work is being funded by the Idaho National Engineering and Environmental Laboratory under a Laboratory Directed Research and Development grant.

Overview

The Smart UXO System has been prototyped and tested at the Idaho National Engineering and Environmental Laboratory (INEEL) under internal Laboratory Directed Research and Development (LDRD) funding through the Department of Energy (DOE). Industry collaboration has been established with AETC and Sanford, Cohen, and Associates (SC&A) for further development and deployment of the Smart UXO System.

Methods for Detection and Classification of UXO

Presently, two different methods are used to detect and classify UXO. The first is the audio detection method referred to as "mag & flag," where a trained UXO operator, using instruments, listens to a variable tone to detect and classify buried targets. This required real-time human interpretation of data. The quality of the analysis is highly dependent upon operator experience and can be impacted by factors such as fatigue and survey techniques. The second method employs the collection and analysis of positioned geophysical sensor data (handheld or vehicular mounts). Targets are detected and classified offline, typically at an offsite facility, then relocated in the field.

While these two approaches to the problem are very different, they both have significant strengths and weakness. Researchers at the INEEL, AETC, and SCA have combined the assets of each approach. This has resulted in the development of a "Smart UXO System."

Development of a "Smart UXO System"

The "Smart UXO System" was designed on the premise that field-operator capabilities can be significantly improved by integrating geophysical sensors with a field-based data acquisition and signal processing system. This system will provide the operator the tools for computer assisted detection and classification of UXO and operate in a field decision-making mode as opposed to offsite analysis. The biases induced from operator interpretation of data would be significantly reduced or eliminated.

Technology Integration. The "Smart UXO System" combines commercially available instrumentation with custom software utilities. The technologies have been integrated into a Field Deployable UXO Detection System. Specific subsystems include:

1) Off-the-shelf geophysical sensors
2) Global Positioning System (GPS) or other sensor positioning technologies
3) Data Acquisition/Signal Processing Unit
4) UXO Operation System Software
5) Data Analysis Algorithms for Detection and Classification of UXO
6) Geophysical Sensor Deployment Cart.

The prototype Field Deployable UXO Detection System uses Department of Defense (DoD) accepted off-the-shelf sensors and navigation components. Total field magnetometers and a differential GPS have been integrated and deployed on a field-portable cart. Integration efforts have been greatly enhanced by collaborating with industrial partners SC&A and AETC. These companies are recognized leaders in the development of signal processing algorithms for detection of UXO and have expert experience in data analysis and field deployment.

Individual components of the system are further described in the following sections.

Geophysical Sensors - Cesium Magnetometer

A system engineering review of several geophysical UXO sensor technologies was performed, including Hall-effect, flux-gate, and magnetometers. Initial prototype efforts have focused on the use of passive magnetometer sensors. Future development efforts are planned to include active electromagnetic sensors.

The magnetometer of choice for this research was a total field Geometrics 822A Cesium magnetometers. The G-822A was initially designed for airborne mobile applications, however, when deployed in a ground survey application, it provides excellent sensitivity at up to 0.0005 nT/Hz RMS. It provides the unique combination of high sensitivity and rapid sampling rates and has excellent performance in a gradiometer configuration. The magnetometer is a self-oscillating, split-beam Cesium vapor device. Tuning through the earth's field range is fully automatic. The sensor/electronics package is watertight, temperature controlled, and delivers full performance under the extreme operating conditions that are encountered in field operations. The output of the magnetometers are interfaced to the electronics module for further signal processing.

The magnetometer sensors were installed onto a low magnetic signature vehicle in various test configurations, as summarized below.

Linear Array Configuration. The linear array configuration employs four Cesium magnetometers, spaced 18 inches apart. This allows the accumulation of high density measurements around each "point of interest." The system then uses specialized algorithms to calculate target characteristics.

Differential Gradient Configuration. Magnetic clutter, varying soil geology, sunspot activity, etc., can cause an ambient field gradient, which often obscures the subtle fluctuations due to detection of UXO. A gradient magnetometer configuration will be employed to reduce these effects. One sensor is removed from the direct region of surveillance and serves as a reference of the baseline ambient field conditions. The second sensor is closely coupled to the region being surveyed. The data from both sensors are electronically mixed, using real-time processing techniques. Common mode noise and extraneous fluctuations are cancelled out and the resulting difference is representative of only signals generated from actual anomalies.

Global Positioning System (GPS)

Technology assessment studies and benchmarks were performed on various GPSs. Critical performance factors that were considered included: time-to-first-fix, number of fixes per second, differential position accuracy, differential speed accuracy, and power consumption.

Several GPS products met the design criteria, however, based on price versus performance, a Trimble AgGPS 123 was selected for installation into the "Smart UXO System." The AgGPS 123 has an integrated dual-channel differential beacon and satellite receiver. This adds the versality of supporting both a private local base station or a commercial satellite-based differential correction service. Both make it possible to calculate submeter positions in real time. The unit includes a high accuracy 12 channel GPS engine with improved ionosphere and troposphere models. The receiver outputs real-time submeter positions and mile-per-hour velocity readings through NMEA-0183 messages. A one pulse per second strobe signal is used to synchronize time with external sensors/instruments. The data stream from the GPS is integrated into the Data Acquisition/Signal Processing Unit using standard RS-232 communication and NMEA format.

Data Acquisition/Signal Processing Unit

The “heart” of the Smart UXO System is the Data Acquisition/Signal Processing Unit (DASP). This unit provides the capability to interface to multiple sensor configurations and supports various protocols, including RS-232, Digital I/O, time domain signals, frequency domain signals, and analog I/O. This will support the future implementation of multisensor systems and sensor fusion. The DASP consists of three modules: Sensor Electronics Module, Data Acquisition/Control Module, and the Data Analysis Unit.

Sensor Electronics Module. The Sensor Electronics Module includes hardware for amplification and filtering of the raw data from the geophysical sensors. The conditioned data are further processed using a Larmor Counter. Count rates are selectable from 100 to 0.1 Hz, or by external cycle command. The counter supports simultaneous operation of up to four separate sensors. The signal is converted to ASCII digital data and transferred to the Data Acquisition/Control Module using RS-232 communication. Specialized circuitry synchronizes the counter to real-time GPS coordinates. All data are time stamped to a common reference.

Data Acquisition/Control Module. The Data Acquisition/Control Module is a multifunction I/O device, which can be programmed to support multiple sensor configurations. Capabilities exist for two channels of RS-232, eight analog inputs, two analog outputs, 24 Digital Inputs or Outputs, and three 16-bit 8 MHZ counters. The module provides complete control of the GPS and magnetometer/counter subsystems.

Data Analysis Unit. The data analysis unit is implemented using a commercial ruggedized laptop computer. The unit is designed around a high-end, Pentium processor and provides all resources for data analysis, data logging, and operation of the Smart UXO System. It was designed to acquire data concurrently from the magnetometers and navigation system. The Data Analysis Unit provides the computing platform for execution of the UXO Operating System software.

UXO Operating System Software

The UXO Operating System (OS) is a Microsoft Windows NT application developed using National Instrument’s Labview software utilities. The OS includes a Graphical User Interface (GUI) (see Figures 1 and 2) for providing the operator tools for real-time review of site survey data, GPS operational status, graphical representation of magnetic data, and interactive analysis of magnetic anomalies caused by buried UXO. In addition, controls are provided for operational configuration and setup of the Smart UXO System.

Integration with Third Party Analysis Tools. LabVIEW incorporates enhanced ActiveX (OLE) functionality. The ActiveX Automation Server allows other applications (such as data analysis algorithms written in C or Visual Basic) to interface and pass data to the UXO Operating System. This provides seamless integration of the advanced data analysis and target recognition routines developed by commercial partners.

Third party analysis tools can also be called using a Dynamic Link Library (DLL), allowing real-time magnetometer data to be processed in the field. Initial tests have demonstrated that AETC's algorithms can be processed in a real-time mode and be used to generate a dynamic array summarizing x-y-z position, projected size of target, and a fit factor based on the dipole model.

The UXO Operating System fully supports multithreading, which is a technology that allows different parts of the application to run independently. This resolves any performance conflicts between user interface, data acquisition, and data analysis. If more complex real-time signature analysis is required, the multithreading can use a field computer with more than one CPU.

GPS Status and Control. A portion of the user interface is devoted to monitoring and control of the GPS. The operator can specify the number of satellites used to compute GPS positions. The preferred operation mode is four or more satellites, making it possible to calculate a three-dimensional position (latitude and longitude, altitude, and time). The receiver can also be configured to use a specific satellite or beacon signal as the primary differential correction source. If the primary signal is lost, the unit is configured to automatically switch to another differential source.

The User Interface includes a Differential Lock status with three GPS quality indicators: (1) no signal, (2) valid signal, but not differential corrected, and (3) differential corrected signal. Based on the signal strength and signal-to-noise ratio, the quality of GPS lock is calculated and displayed. The GPS time values are displayed in universal time coordinates. Other visual/audio alarms alert the operator of loss of GPS differential lock and a timeout status if the signal is not updated at least every 2 seconds.

The latitude and longitude coordinates are displayed at a 1-second refresh rate. The coordinates are presented using the NAD-83 datum and corrected to Idaho State Plane system. This allows all field data to be correlated and overlaid to existing data or maps.

The GPS provides an indication of speed over ground (SOG) in knots. These data are converted to ft/sec and recorded on the GUI using a bar indicator. Speed thresholds can be configured to pace the operator during the collection of field data.

Real-Time Data Display. A major portion of the GUI supports graphical plotting of magnetometer sensor data as a function of x,y coordinates. The data are represented in a standard geophysical gradient format, where the data are separated into six bins and color coded as a function of signal magnitude. Operator controls are available for background correction of the data sets and configuration of the bin sizes. Additional controls are available to scale and zoom the spectra. The display provides live tracing of the GPS path of travel and can notify the operator if he diverges from assigned survey lanes.

As advanced detection and classification algorithms are integrated into the UXO Operation System, additional menu functions and drop-down graphic windows will be added. A planned feature is a window that includes a plot of suspected UXO, with depth prediction, size estimation, and probability/confidence level assignment.

Data Logging. The UXO Operating System supports two data logging modes. First, the system automatically generates data files for archiving of site survey data for use in postprocessing applications and/or generating of maps. Second, the system provides real-time transfer of data to analysis routines using dynamic link libraries or ActiveX controls. This feature allows sensor data to be analyzed in the field on the fly.

Advanced Features. The UXO Operation System supports NI-DAQ Remote Device Access. This feature typically is used to acquire data from multiple data acquisition systems/sensors using remote computers over a network. Conceptually, this feature could be used to network UXO sensors. For example, multiple UXO Detection systems could be deployed into the field and independently collect magnetometer data in adjacent lanes. By using off-the-shelf wireless network technology, all the systems could be networked to a central data analysis computer. This wide profile would allow real-time correction and validation of electromagnetic anomalies from regional clutter. Signals generated from known features such as fence lines, rock out cropping, etc., could be differentially compared to adjacent lanes in a real-time mode and used to improve common mode rejection of noise. The confidence of detection of a suspected target could be improved by analyzing and comparing adjacent lanes in a real-time mode. In effect, you could deploy multiple UXO Detection Systems and have them operate as a virtual single system with all sensors dynamically linked into a single large array.

Data Analysis Algorithms for Detection and Classification of UXO

In collaboration with SC&A and AETC, the behavior of sensor response to potential UXO targets is being further analyzed and modeled. Specialized analysis methods are under development to extract key features used to detect and classify UXO. Critical design parameters include the ability for automatic estimation of target X-Y position, depth, and size. In addition, the analysis tools are capable of discriminating ordnance anomalies from background noise. Several analysis techniques are in the process of being evaluated, including: (1) analytical model matching, (2) artificial neural network, (3) database lookup of signatures, and (4) automatic target recognition (ATR). Initial prototype efforts have focused on the integration of AETC's analytical model, which employs a proprietary Maximum Likelihood Dipole Fit Algorithm.

AETC's algorithms are optimized to locate and characterize UXO based on total field magnetometer measurements. In the presence of the earth's ambient magnetic field, any UXO material will develop a magnetic moment from induced magnetic effects. The inducing field transforms the object into a temporary dipole magnet, with corresponding north and south poles. The shape of the UXO will impact the magnitude and configuration of the induced field, resulting in a unique magnetic signature.

Preliminary results have demonstrated that the magnetic signature of ordnance can be completely modeled as a magnetic dipole. The strength and direction of the measured dipole moment scale as a function of ordnance size, orientation, and permanent magnetization. Experience shows that an effective ordnance size can be calculated within 20–30% of the actual ordnance diameter. Field demonstration tests are planned and will be used to further validate the algorithms.

The overall objective is to employ data analysis techniques to provide the field operator the tools to achieve offsite "laboratory level" detection rates while in the field. Instead of concentrating on collecting better data from better sensors, the analysis techniques focused on analyzing real-world data from available sensors.

Geophysical Sensor Deployment Cart

SC&A designed a cart (see Figure 3) to serve as the platform for the Smart UXO System. It is constructed of composite materials producing essentially noise-free data. Adjustable sensor boom configurations allow for various array configurations to be deployed. The boom also supports sensors mounted in a gradiometer configuration. The ergonomic design of the system allows for easy and efficient deployment while being rugged enough to endure harsh, real-world field conditions.

Preliminary INEEL Research Results

Partnerships have been established with “experts-in-the-field” to fully develop and optimize “real-time” UXO data analysis methods. A Field Deployable UXO Detection System has been built and is providing a state-of-the-art platform for further testing and development of technology. Preliminary research results support the concept that a Smart UXO System can provide real-time, computer aided detection and classification capabilities to the field operator. Tests demonstrate that geophysical data can be efficiently collected and processed in the field, eliminating the need to postprocess the data. Further testing of this technology will be conducted at the INEEL and later at a military test site.

Future Developments

The Smart UXO System was designed to be fully compatible with off-the-shelf sensors, including total field magnetometers, vector and total field gradiometers, electromagnetic sensors, and time domain pulsed induction devices. Future research will develop a multisensor system and attempt to demonstrate additional improvements from high performance sensor fusion. Proposed efforts include packaging the technology into a man portable device. Other commercial partners may be considered for manufacture and marketing of the completed system.

SUMMARY

Efforts are well under way to demonstrate a field-based, computer-assisted, UXO target detection and classification system. Field tests are scheduled to further demonstrate and validate signal processing algorithms for enhanced detection, location, and discrimination of buried UXOs under a wide range of environmental conditions. Initial tests will be performed at designated sites at the INEEL.

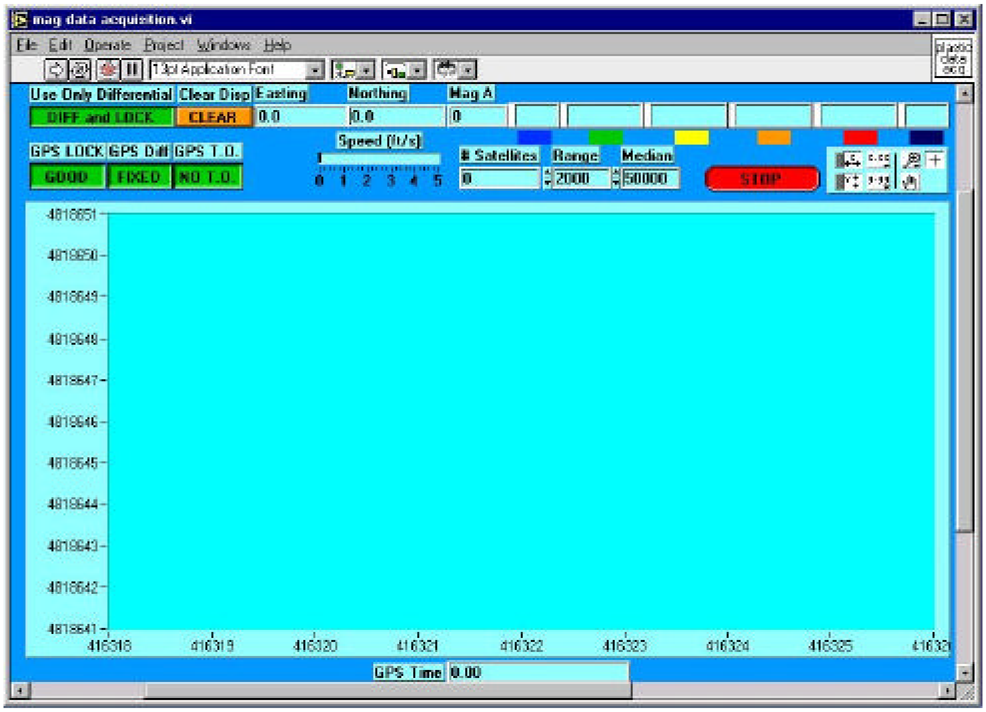

Figure 1. UXO Operating System User Display.

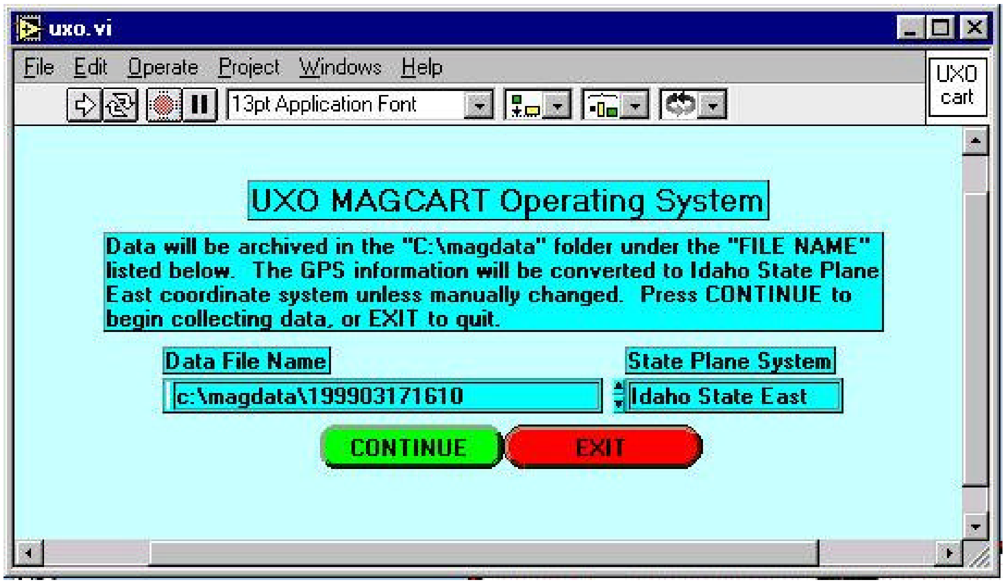

Figure 2.

Figure 3. SC&A cart.